METHOD AND APPARATUS FOR TIME EFFICIENT RETRANSMISSION USING SYMBOL ACCUMULATION

Claim of Priority under 35 U.S.C. §120

[1001] The present Application for Patent claims priority and is a continuation application to Patent Application No. 09/588,434, entitled, "Method and Apparatus For Time Efficient Retransmission Using Symbol Accumulation," filed June 6, 2000, which is a divisional application of U.S. Patent No. 6,101,168, issued August 8, 2000, granted on Patent Application No. 08/969,319, filed November 13, 1997, assigned to the assignee hereof, and hereby expressly incorporated by reference herein.

BACKGROUND

Field

[1001] The present invention relates to data communication. More particularly, the present invention relates to a novel and improved method and apparatus for the efficient retransmission of data using symbol accumulation.

Background

[1002] The use of code division multiple access (CDMA) modulation techniques is one of several techniques for

facilitating communications in which a large number of system users are present. Other multiple access communication system techniques, such as time division multiple access (TDMA) and frequency division multiple access (FDMA) are known in the art. However, the spread spectrum modulation techniques of CDMA has significant advantages over other modulation techniques for multiple access communication systems. The use of CDMA techniques in a multiple access communication system is disclosed in U.S. Patent No. 4,901,307, entitled "SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM USING SATELLITE OR TERRESTRIAL REPEATERS," assigned to the assignee of the present invention and is incorporated by reference herein. The use of CDMA techniques in a multiple access communication system is further disclosed in U.S. Patent No. 5,103,459, entitled "SYSTEM AND METHOD FOR GENERATING SIGNAL WAVEFORMS IN A CDMA CELLULAR TELEPHONE SYSTEM," also assigned to the assignee of the present invention and is incorporated by reference herein. Furthermore, the CDMA system can be designed to conform to the "TIA/EIA/IS-95A Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System", hereinafter referred to as the IS-95A standard.

[1003] CDMA, by its inherent nature of being a wideband signal, offers a form of frequency diversity by spreading the signal energy over a wide bandwidth. Therefore,

frequency selective fading affects only a small part of the CDMA signal bandwidth. Space or path diversity is obtained by providing multiple signal paths through simultaneous links to a mobile user or remote station through two or more base stations. Furthermore, path diversity may be obtained by exploiting the multipath environment through spread spectrum processing by allowing signals arriving with different propagation delays to be received and processed separately. Examples of improved demodulation using path diversity are illustrated in U.S. Patent No. 5,101,501 entitled "METHOD AND SYSTEM FOR PROVIDING A SOFT HANDOFF IN COMMUNICATIONS IN A CDMA CELLULAR TELEPHONE SYSTEM," and U.S. Patent No. 5,109,390 entitled "DIVERSITY RECEIVER IN A CDMA CELLULAR TELEPHONE SYSTEM," both assigned to the assignee of the present invention and incorporated by reference herein.

[1004] The reverse link refers to a transmission from a remote station to a base station. On the reverse link, each transmitting remote station acts as an interference to other remote stations in the network. Therefore, the reverse link capacity is limited by the total interference which a remote station experiences from other remote stations. The CDMA system increases the reverse link capacity by transmitting fewer bits, thereby using less power and reducing interference, when the user is not speaking.

[1005] The forward link refers to a transmission from a base station to a remote station. On the forward link, the transmission power of the base station is controlled for several reasons. A high transmission power from the base station can cause excessive interference with other base stations. Alternatively, if the transmission power of the base station is too low, the remote station can receive erroneous data transmissions. Terrestrial channel fading and other known factors can affect the quality of the forward link signal as received by the remote station. As a result, the base station attempts to adjust its transmission power of signal to each remote station to maintain the desired level of performance at the remote station.

[1006] The forward link and reverse link are capable of data transmission at variable data rates. A method for transmitting data in data packets of fixed size, wherein the data source provides data at a variable data rate, is described in detail in U.S. Patent No. 5,504,773, entitled "METHOD AND APPARATUS FOR THE FORMATTING OF DATA FOR TRANSMISSION", assigned to the assignee of the present invention and incorporated by reference herein. Data is partitioned into data packets (or packets) and each data packet is then encoded into an encoded packet. Typically, the encoded packets are of a predetermined duration. For example, in accordance with the IS-95A standard for the

forward link, each encoded packet is 20 msec wide and, at the 19.2Ksps symbol rate, each encoded packet contains 384 symbols. A rate 1/2 or a rate 3/4 convolutional encoder is used to encode the data, depending on the application. Using a rate 1/2 encoder, the data rate is approximately 9.6Kbps. At the 9.6Kbps data rate, there are 172 data bits, 12 cyclic redundancy check (CRC) bits and 8 code tail bits per data packet.

[1007] At lower data rates, such as 4.8Kbps, 2.4Kbps, or 1.2Kbps, the code symbols within the encoded packet is repeated N_S number of times to maintain a constant 19.2Ksps symbol rate. Symbol repetition is performed to provide time diversity which improves the decoding performance in an impaired channel. To minimize the transmission power and increase system capacity, the transmission power level of each symbol is scaled in accordance with the repetition rate N_S.

[1008] In accordance with the IS-95A standard, each data packet is block encoded with a CRC polynomial and then convolutionally encoded. The encoded packet is transmitted from the source device to the destination device. At the destination device, the received packet is demodulated and convolutionally decoded with a Viterbi decoder. The decoded data is then checked by a CRC checker to determine if the received packet has been decoded correctly or in error. The CRC check is only able to determine whether an

error within the decoded packet is present. The CRC check is not able to correct the error. Therefore, another mechanism is required to allow correction of the data packets received in error.

SUMMARY

[1009] *The present invention is a novel and improved* method and apparatus for the efficient retransmission of data using symbol accumulation. In the present invention, data transmission occurs from a source device to a destination device in the nominal manner. The destination device *receives* the data *transmission,* demodulates the signal, and decodes the data. In the exemplary embodiment, the data is partitioned into data packets which are transmitted within one frame time period. As part of the decoding process, the destination device performs the CRC check of the data packet to determine whether the packet was received in error. In the exemplary embodiment, if the packet was received in error, the destination device transmits a NACK message to the source device.

[1010] In the exemplary embodiment, the source device responds to the NACK message by retransmitting the packet received in error concurrently with the transmission of the new data packet. The destination device receives the data transmission and retransmission, demodulates the signal,

and separates the received data into the new packet and the retransmitted packet. The destination device then accumulates the energy of the received retransmitted packet with the energy already accumulated by the destination device for the packet received in error. The destination device then attempts to decode the accumulated data packet. The accumulation of the additional energy provided by the subsequent retransmissions improves the probability of a correct decoding. Alternately, the destination device can decode the retransmitted packet by itself without combining the two packets. In both cases, the throughput rate can be improved since the packet received in error is retransmitted concurrently with the transmission of the new data packet.

[1011] It is an object of the present invention to maintain the throughput rate of a communication system in the presence of channel impairments. In the exemplary embodiment, a data packet which is received in error is retransmitted by the source device concurrently with the new data packet within the same time period. Alternately, the packet received in error can be retransmitted on an additional traffic channel which is independent of the traffic channel used to transmit the new packet. Since the retransmitted packet does not delay or impede the transmission of the new packet, the throughput rate is

maintained during the retransmission of the packet received in error.

[1012] It is another object of the present invention to maximize the capacity of the communication channel by retransmitting the packet received in error with the minimum amount of energy such that the accumulation of the energy of the transmission and retransmission results in the correct decoding of the packet. The packet received in error can be retransmitted with less energy-per-bit than the new packet which is transmitted for the first time. At the destination device, the energy of each symbol in the packet received in error is accumulated with the energy of each symbol in the retransmitted packet. The accumulated symbols are then decoded.

[1013] It is yet another object of the present invention to improve the performance of the decoding of the packets received in error by performing the maximal ratio combining of the transmitted and retransmitted packets. For a communication system which supports coherent demodulation with the use of a pilot signal, the destination device performs a dot product of the received symbols with the pilot signal. The dot product weighs each symbol in accordance with the signal strength of the received signal and results in the maximal ratio combining. Within a transmission or a retransmission, the scalar values from each dot product circuit which has been assigned to a

signal path are coherently combined to obtain combined scalar values. The combined scalar values from multiple transmission and retransmissions are also coherently combined. The dot product and coherent combination improve the performance of the subsequent decoding step. For a communication system which does not transmit a pilot signal, the symbols from multiple transmission and retransmissions are scaled according to the received signal-to-noise ratios of the received transmission or retransmissions before accumulation.

BRIEF DESCRIPTION OF THE DRAWINGS

[1014] The features, objects, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

[1015] FIG. 1 is an exemplary diagram of the communication system of the present invention showing a plurality of base stations in communication with a remote station;

[1016] FIG. 2 is a block diagram of an exemplary base station and an exemplary remote station;

[1017] FIG. 3 is a block diagram of an exemplary forward traffic channel transmission system;

[1018] FIG. 4 is an exemplary block diagram of an alternative modulator;

[1019] FIG. 5 is a block diagram of an exemplary convolutional encoder;

[1020] FIG. 6 is a block diagram of an exemplary demodulator within the remote station;

[1021] FIG. 7 is a block diagram of an exemplary pilot correlator;

[1022] FIG. 8 is a block diagram of an exemplary decoder within the remote station; and

[1023] FIG. 9 is a block diagram of an exemplary architecture which supports data transmission over multiple code channels.

DETAILED DESCRIPTION

[1024] For simplicity, the following discussion details the transmission and retransmission of data packets from a source device to a destination device without regard to whether the source device is a base station **4** or a remote station **6**. The present invention is equally applicable for data transmission by base station **4** on the forward link and data transmission by remote station **6** on the reverse link.

I. Circuit Description

[1025] Referring to the figures, FIG. 1 represents an exemplary communication system of the present invention which is composed of multiple base stations **4** in communication with multiple remote stations **6** (only one remote station **6** is shown for simplicity). System controller **2** connects to all base stations **4** in the communication system and the public switched telephone network (PSTN) **8**. System controller **2** coordinates the communication between users connected to PSTN **8** and users on remote stations **6**. Data transmission from base station **4** to remote station **6** occurs on the forward link through signal paths **10** and transmission from remote station **6** to base station **4** occurs on the reverse link through signal paths **12**. The signal path can be a straight path, such as signal path **10a**, or a reflected path, such as signal path **14**. Reflected path **14** is created when the signal transmitted from base station **4a** is reflected off reflection source **16** and arrives at remote station **6** through a different path than the straight path. Although illustrated as a block in FIG. 1, reflection source **16** is an artifact in the environment in which remote station **6** is operating, e.g. a building or other structures.

[1026] An exemplary block diagram of base station **4** and remote station **6** of the present invention is shown in FIG.

2. Data transmission on the forward link originates from data source **120** which provides the data, in data packets, to encoder **122**. An exemplary block diagram of encoder **122** is shown in FIG. 3. Within encoder **122**, CRC encoder **312** block encodes the data with a CRC polynomial which, in the exemplary embodiment, conforms to the IS-95A standard. CRC encoder **312** appends the CRC bits and inserts a set of code tail bits to the data packet. The formatted data packet is provided to convolutional encoder **314** which convolutionally encodes the data and provides the encoded data packet to symbol repeater **316**. Symbol repeater **316** repeats the encoded symbols N_S times to provide a constant symbol rate at the output of symbol repeater **316** regardless of the data rate of the data packet. The repeated data is provided to block interleaver **318** which reorders the symbols and provides the interleaved data to modulator (MOD) **124**. A block diagram of an exemplary modulator **124a** is shown if FIG. 3. Within modulator **124a**, the interleaved data is spread by multiplier **330** with the long PN code which identifies the remote station **6** to which the data is transmitted. The long PN spread data is provided to multiplier **332** which covers the data with the Walsh code corresponding to the traffic channel assigned to remote station **6**. The Walsh covered data is further spread with the short PNI and PNQ codes by multipliers **334a** and **334b**. The short PN spread data is provided to transmitter (TMTR)

126 (see FIG. 2) which filters, modulates, and amplifies the signal. The modulated signal is routed through duplexer **128** and transmitted from antenna **130** on the forward link through signal path **10**.

[1027] A block diagram of an alternative modulator **124b** is shown in FIG. 4. In this embodiment, data source **120** provides data packets to two encoders **122** which encode the data as described above. The interleaved data and the pilot and control data are provided modulator **124b**. Within modulator **124b**, the interleaved data from the first encoder **122** is provided to Walsh modulator **420a** and the interleaved data from the second encoder **122** is provided to Walsh modulator **420b**. Within each Walsh modulator **420**, the data is provided to multiplier **422** which covers the data with a Walsh code assigned to that Walsh modulator **420**. The covered data is provided to gain element **424** which scales the data with a scaling factor to obtain the desired amplitude. The scaled data from Walsh modulators **420a** and **420b** are provided to summer **426** which sums the two signals and provides the resultant signal to complex multiplier **430**. The pilot and control data are provided to multiplexer (MUX) **412** which time multiplexes the two data and provides the output to gain element **414**. Gain element **414** scales the data to obtain the desired amplitude and provides the scaled data to complex multiplier **430**.

[1028] Within complex multiplier **430**, the data from gain element **414** is provided to multipliers **432a** and **432d** and the data from summer **426** is provided to multipliers **432b** and **432c**. Multipliers **432a** and **432b** spread the data with the spreading sequence from multiplier **440a** and multipliers **432c** and **432d** spread the data with the spreading sequence from multiplier **440b**. The output of multipliers **432a** and **432c** are provided to summer **434a** which subtracts the output of multiplier **432c** from the output of multiplier **432a** to provide the I channel data. The output of multipliers **432b** and **432d** are provided to summer **434b** which sums the two signals to provide the Q channel data. The spreading sequences from multipliers **440a** and **440b** are obtained by multiplying the PNI and PNQ codes with the long PN code, respectively.

[1029] Although modulator **124b** as shown in FIG. 4 support transmission of two traffic channels which are labeled as the fundamental channel and the supplemental channel, modulator **124b** can be modified to facilitate transmission of additional traffic channels. In the description above, one encoder **122** is utilized for each traffic channel. Alternatively, one encoder **122** can be utilized for all traffic channels, with the output of encoder **122** demultiplexed into multiple data streams, one data stream for each traffic channel. Various modifications of the encoder and modulator as described above can be

contemplated and are within the scope of the present invention.

[1030] At remote station **6** (see FIG. 2), the forward link signal is received by antenna **202**, routed through duplexer **204**, and provided to receiver (RCVR) **206**. Receiver **206** filters, amplifies, demodulates, and quantizes the signal to obtain the digitized I and Q baseband signals. The baseband signals are provided to demodulator (DEMOD) **208**. Demodulator **208** despreads the baseband signals with the short PNI and PNQ codes, decovers the despread data with the Walsh code identical to the Walsh code used at base station **4**, despreads the Walsh decovered data with the long PN code, and provides the demodulated data to decoder **210**.

[1031] Within decoder **210** which is shown in FIG. 8, block de-interleaver **812** reorders the symbols within the demodulated data and provides the de-interleaved data to Viterbi decoder **814**. Viterbi decoder **814** convolutionally decodes the de-interleaved data and provides the decoded data to CRC check element **816**. CRC check element **816** performs the CRC check and conditionally provides the checked data to data sink **212**.

[1032] Data transmission from remote station **6** to base station **4** on the reverse link can occur in one of several embodiments. In the first embodiment, the reverse link transmission can occur over multiple orthogonal code channels similar to the structure used for the forward

link. The exemplary embodiment of a remote transmission system which supports multiple code channels on the reverse link is described in detail in U.S. Patent No. 5,930,230, entitled "HIGH DATA RATE CDMA WIRELESS COMMUNICATION SYSTEM", assigned to the assignee of the present invention and incorporated by reference herein. A simplified block diagram of the structure is shown in FIG. 9. Data source **230** provides the data, in data packets, through DEMUX **912** to channel encoders **910**. Within each channel encoder **910**, CRC encoder **914** block encodes the data packet then appends the CRC bits and a set of code tail bits to the data. The formatted data packet is provided to convolutional encoder **916** which convolutionally encodes the data and provides the encoded data packet to symbol repeater **918**. Symbol repeater **918** repeats the symbols with the encoded data packet N_S times to provide a constant symbol rate at the output of symbol repeater **918** regardless of the data rate. The repeated data is provided to block interleaver **920** which reorders the symbols within the repeated data and provides the interleaved data to modulator (MOD) **234**.

[1033] Within modulator **234**, the interleaved data from each channel encoder **910** is provided to a Walsh modulator **930**. Within Walsh modulator **930**, the interleaved data is covered by multiplier **932** with the Walsh code which identifies the code channel of the set of code channels transmitted by the remote station on which the data is

transmitted. The Walsh covered data is provided to gain adjust **934** which amplifies the data with the desired gain setting for the code channel. The outputs from Walsh modulators **930** are provided to complex PN spreader **940** which spreads the Walsh covered data with the long PN code and the short PN codes. The modulated data is provided to transmitter **236** (see FIG. 2) which filters, modulates, and amplifies the signal. The modulated signal is routed through duplexer **204** and transmitted from antenna **202** on the reverse link through signal path **12**. A more detailed description of the reverse link architecture can be obtained from the aforementioned U.S. Patent No. 5,930,230.

[1034] In the second embodiment, the reverse link is defined in accordance with the IS-95A standard. In essence, the reverse link transmission by remote station **6** is defined in accordance with the temporal offset of a common long PN sequence generator. At two differing offsets the resulting modulation sequences are uncorrelated. The offset of each remote station **6** is determined in accordance with a unique numerical identification of the remote station **6**, which in the exemplary embodiment of an IS-95A remote station **6** is the electronic serial number (ESN). Thus, each remote station **6** transmits on one uncorrelated reverse link channel determined in accordance with its unique electronic serial number.

[1035] The reverse link structure of the second embodiment is fully described in the aforementioned U.S. Patent No. 4,901,307. In summary, the data packets are provided by data source **230** to encoder **232** which encodes the data packets with a CRC block code and a convolutional code. The encoded data is repeated to maintain a constant symbol rate regardless of the data rate. Six symbols of encoded data are mapped into a 64-bit Walsh symbol. The mapped signal is spread by the long PN code and the short PN codes. The modulated data is provided to transmitter **236** which performs the same function as that described in the first embodiment.

II. Demodulation of the Data Symbols

[1036] An exemplary block diagram illustrating the circuit for demodulating the received signal is shown in FIG. 6. The digitized I and Q baseband signals from receiver **150** or **206** are provided to a bank of correlators **610**. Each correlator **610** can be assigned to a different signal path from the same source device or a different transmission from a different source device. Within each assigned correlator **610**, the baseband signals are despread with the short PNI and PNQ codes by multipliers **620**. The short PNI and PNQ codes within each correlator **610** can have a unique offset corresponding to the propagation delay experienced by the signal being demodulated by that correlator **610**.

The short PN despread data is decovered by multipliers **622** with the Walsh code assigned to the traffic channel being received by the correlator **610**. The decovered data is provided to filters **624** which accumulate the energy of the decovered data over a Walsh symbol period.

[1037] The short PN despread data from multipliers **620** also contains the pilot signal. In the exemplary embodiment, at the source device, the pilot signal is covered with the all zero sequence corresponding to Walsh code 0. In the alternative embodiment, the pilot signal is covered with an orthogonal pilot sequence as described in U.S. Patent No. 6,285,655, entitled "METHOD AND APPARATUS FOR PROVIDING ORTHOGONAL SPOT BEAMS, SECTORS, AND PICOCELLS", assigned to the assignee of the present invention and incorporated by reference herein. The short PN despread data is provided to pilot correlator **626** which perform pilot decovering, symbol accumulation, and lowpass filtering of the despread data to remove the signals from other orthogonal channels (e.g. the traffic channels, paging channels, access channels, and power control channel) transmitted by the source device. If the pilot is covered with Walsh code 0, no Walsh decovering is necessary to obtain the pilot signal.

[1038] A block diagram of an exemplary pilot correlator **626** is shown in FIG. 7. The despread data from multiplier **620** is provided to multiplier **712** which decovers the

despread data with the pilot Walsh sequence. In the exemplary embodiment, the pilot Walsh sequence corresponds to Walsh code 0. However, other orthogonal sequences and be utilized and are within the scope of the present invention. The decovered data is provided to symbol accumulator **714**. In the exemplary embodiment, symbol accumulator **714** accumulates the decovered symbols over the length of the pilot Walsh sequence which, for IS-95 Walsh sequence, is 64 chips in duration. The accumulated data is provided to lowpass filter **716** which filters the data to remove noise. The output from lowpass filter **716** comprises the pilot signal.

[1039] The two complex signals (or vectors) corresponding to the filtered pilot signal and the filtered data symbols are provided to dot product circuit **630** which computes the dot product of the two vectors in a manner well known in the art. In the exemplary embodiment, dot product circuit **630** is described in detail in U.S. Patent No. 5,506,865, entitled "PILOT CARRIER DOT PRODUCT CIRCUIT", assigned to the assignee of the present invention and incorporated by reference herein. Dot product circuit **630** projects the vector corresponding to the filtered data symbol onto the vector corresponding to the filtered pilot signal, multiplies the amplitude of the vectors, and provides a signed scalar value to combiner **640**.

[1040] The pilot signal from each correlator **610** reflects the signal strength of the signal path received by that correlator **610**. Dot product circuit **630** multiplies the amplitude of the vector corresponding to the filtered data symbols, the amplitude of the vector corresponding to the filtered pilot signal, and the cosine of the angle between the vectors. Thus, the output from dot product circuit **630** corresponds to the energy of the received data symbol. The cosine of the angle between the vectors (e.g., the angle of the pilot minus the angle of the traffic) weighs the output in accordance with the noise in both pilot and traffic vectors.

[1041] Combiner **640** receives the scalar values from each correlator **610** which has been assigned to a signal path and combines the scalar values. In the exemplary embodiment, combiner **640** coherently combines the scalar values for each received symbol. An exemplary embodiment of combiner **640** is described in detail in U.S. Patent No. 5,109,390, entitled "DIVERSITY RECEIVER IN A CDMA CELLULAR TELEPHONE SYSTEM," assigned to the assignee of the present invention and incorporated by reference herein. Coherent combination takes into account the sign of the scalar output from each correlator **610** and results in the maximal ratio combining of the received symbols from different signal paths. The combined scalar value from combiner **640** is represented as an m-bit soft decision value for subsequent demodulation

and decoding. The soft decision values are provided to multiplier **642** which despreads the soft decision values with the long PN code to produce the demodulated data. The demodulated data is decoded in the manner described above.

[1042] In a communication system in which the pilot signal is not transmitted by the source device, the dot product is not performed. Combiner **640** simply combines the measured amplitude (or energy) of the received signal from filters **624**.

III. Acknowledgment Procedures

[1043] With the CRC check, the destination device is able to determine whether the data packet was received in a condition capable of correction by the Viterbi decoder. In the present invention, one of a number of protocols can be used to control the retransmission of packets received in error. The following embodiments list some of the methods that can be used. Other methods are extensions of the present invention and are within the scope of the present invention.

[1044] In the first embodiment, the destination device acknowledges every received packet and sends an ACK message back to the source device if the packet is received correctly or a NACK message if the packet is received in error. For each transmitted packet, the source device monitors the ACK and NACK messages and retransmits the

packets received in error. In this embodiment, the source device can retransmit a packet if an ACK or NACK message for that packet is not received within a predetermined time period. Furthermore, the source device can terminate the retransmission of a packet if an ACK or NACK message is not received after a predetermined number of retransmissions.

[1045] In the second embodiment, the destination device acknowledges every received packet with an ACK or NACK message as in the first embodiment. The messages are sent by the destination device in an ordered manner to the source device. Therefore, if the source device recognizes that a message has not been received for a packet, the source device retransmits that packet. For example, if the source device receives a message for packet i+1 but has not received a message for packet i, then the source device realizes that either packet i or the message for packet i was not received properly. Therefore, the source device retransmits packet i. The second embodiment is an extension of the first embodiment which can be used to speed up the retransmission process.

[1046] In the third embodiment, the destination device acknowledges only packets which are received in error with the NACK messages. The source device only retransmits a packet if a NACK message is received. The destination device can retransmit the NACK message (e.g., if a

retransmission has not been received correctly after a predetermined time period).

IV. Data Retransmission

[1047] In the exemplary embodiment, if a packet was received in error, the destination device transmits a NACK message back to the source device. The packet received in error can be retransmitted concurrently with the new packet in the current frame or at a subsequent frame. Preferably, the packet received in error is retransmitted in the current frame to minimize processing delays. In the exemplary embodiment, the retransmitted packet comprises the identical code symbols which were transmitted previously. In the alternative embodiment, the retransmitted packet comprises new code symbols.

[1048] A block diagram of an exemplary convolutional encoder **314** of the present invention is shown in FIG. 5. In the exemplary embodiment, convolutional encoder **314** is a constraint length K=9 encoder, although other constraint lengths can also be utilized. The input bits are provided to (K-1) delay elements **512**. The outputs from selected delay elements **512** are provided to a set of summers **514** which perform modulo two addition of the inputs to provide the generator output. For each summer **514**, the delay elements **512** are selected based on a polynomial which is carefully chosen for high performance.

[1049] In the exemplary embodiment wherein the retransmitted packet comprises the identical code symbols which were transmitted previously, convolutional encoder **314** is designed for the necessary code rate. For example, for a rate 1/2 convolutional encoder **314**, only two generators (e.g., g0 and g1 from summers **514a** and **514b**, respectively) are necessary and the remaining generators can be omitted. At the receiver, the code symbols for the retransmitted packets can be combined with the corresponding code symbols from prior transmissions or can replace those prior transmitted symbols. The increased energy from symbol accumulation results in improved decoding performance at the receiver.

[1050] In the alternative embodiment wherein the retransmitted packet comprises new code symbols which may not have been transmitted previously, convolutional encoder **314** is designed to produce code symbols at various code rates. Referring to FIG. 5, for an exemplary rate 1/2 convolutional encoder **314**, each input bit results in two output code symbols (e.g., from generators g0 and g1). The original transmission can comprise the code symbols for the original code rate (e.g., code symbols from generator g0 and g1 for rate 1/2). If this packet is received in error, the retransmitted packet can comprise the code symbols from other generators which have not been transmitted previously (e.g., generators g2 and/or g3). At the receiver, the code

symbols for the retransmitted packets are interleaved (not combined) with the corresponding code symbols from prior transmissions. The Viterbi decoder then decodes the accumulated packet (comprising the code symbols from the transmitted and retransmitted packets) using a code rate corresponding to the accumulated packet. As an example, assume the original transmission utilizes rate 1/2 and the Viterbi decoder originally decodes using rate 1/2. Assume further that the packet was received in error. The retransmitted packet can comprise the code symbols from generator g2. In this case, the Viterbi decoder would decode the received codes symbols from generators g0, g1, and g2 using rate 1/3. Similarly, if the accumulated packet is decoded in error, an additional retransmitted packet comprising codes symbols from generator g3 can be transmitted and the Viterbi decoder would decode the accumulated packet comprising codes symbols from generators g0, g1, g2 and g3 using rate 1/4. The lower code rates provide enhanced error correcting capabilities over the original rate 1/2.

[1051] Other code rates can also be generated by using punctured codes and are within the scope of the present invention. Punctured codes are thoroughly treated by J. Cain, G. Clark, and J. Geist in "Punctured Convolutional Codes of Rate (n-1)/n and Simplified Maximum Likelihood Decoding," IEEE Transaction on Information Theory, IT-25,

pgs. 97-100, Jan. 1979. As an example, the original transmission can comprise the code symbols from generators g0 and g1 for rate 1/2 and the retransmission can comprise code symbols from generators g2 and g3 which have been punctured to rate 3/4. The accumulated packet from both transmissions would comprise code symbols from generators g0, g1, g2 and g3 having a punctured rate 3/10. Puncturing reduces the number of code symbols to be retransmitted but also reduces the error correcting capability of the convolutional code.

[1052] In communication systems wherein the symbol rate can not be increased to accommodate the additional retransmitted symbols, the source device can change the code rate of the convolutional encoder to decrease the number of code symbols needed for the new packet. The saving in code symbols can then be used for the retransmitted packet. For example, a data packet comprising 192 bits can be encoded nominally using a rate 1/2 code to generate 384 code symbols. To retransmit a packet concurrently with the transmission of a new packet, the new packet can be encoded with a rate 3/4 code, resulting in the generation of 256 code symbols. The remaining 128 code symbols can comprise the retransmitted packet.

[1053] Using this scheme whereby the code rate of the new packet can be adjusted, it may be possible to operate

symbol repetition in the nominal manner. Since the code rate is decreased, a higher operating E_S/I_O is probably required to maintain the same level of performance. The transmission power level can be adjusted such that the E_S of each symbol is increased to maintain the requisite level of performance. This scheme is especially useful to avoid additional delay when the data rate of the new packet is at full rate.

[1054] The source device can retransmit the packet received in error in one of many embodiments. In the first embodiment, the retransmission is achieved by substituting the repeated symbols for the new packet with the code symbols for the retransmitted packet. For example, if there are 384 symbols in a frame and 288 of the symbols are repeated, then these 288 symbols can be used for the code symbols for the retransmitted packet. At least 96 symbols are reserved for the code symbols for the new packet. If the retransmitted packet improves the decoding by the destination device and results in an error free data packet, then the retransmission does not degrade the throughput rate even in the presence of errors in the channel.

[1055] The probability of a packet received in error is dependent on the quality, as measured by the energy-per-bit-to-noise-plus-interference ratio (E_S/I_O), of the

received signal and the variation of the signal quality over time. The energy-per-bit E_S is determined by the amount of energy received over a symbol period. If the repeated symbols are used for the code symbols for the retransmitted packet, the symbol periods for the new symbols and the retransmitted symbols are shortened correspondingly. If the transmission power is maintained at the same level by the source device, the E_S will be lower for each new and retransmitted symbol and can result in a higher error rate. To maintain the same E_S over a shorter symbol period, the transmission power level of the symbols is increased. In fact, the transmission power level can be increased such that the E_S is higher than nominal to compensate for the loss in time diversity that results from not repeating the symbols.

[1056] The transmission power level can be increased by the same amount for the new and retransmitted symbols, or by different amounts. This choice is determined by system considerations. If the transmission power level is increased sufficiently for the retransmitted symbols, the destination device can decode the retransmitted packet without regard to the original packet which was received in error. However, higher transmission power consumes system resources and can decrease the system capacity. In the preferred embodiment, the transmission power level is

adjusted such that the E_S for the retransmitted symbols is lower than that of the new symbols. Furthermore, the transmission power level for the retransmitted symbols can be set at or slightly above the minimal level such that the energy of the retransmitted symbols, when combined with the energy already accumulated by the destination device for those symbols, results in the requisite level of performance.

[1057] The minimum transmission power level for the retransmitted symbols can be computed as follows. First, the communication system determines the E_S/I_O required for the requisite level of performance. The required E_S/I_O is approximately equal to an E_S/I_O set point maintained by the power control loop. The power control loop adjusts the transmission power to maintain the quality of the received signal at the E_S/I_O set point. Second, the destination device can measure the signal-to-noise-plus-interference ratio $\frac{S}{\sqrt{S^2+N^2}}$ of the received signal. From $\frac{S}{\sqrt{S^2+N^2}}$, the E_S/I_O of the received packet can be calculated. An exemplary embodiment for measuring the E_S/I_O in a spread spectrum communication system is described in detail in U.S. Patent No. 5,903,554, entitled "METHOD AND APPARATUS FOR MEASURING LINK QUALITY IN A SPREAD SPECTRUM COMMUNICATION SYSTEM", assigned to the assignee of the

present invention and incorporated by reference herein. The destination device can then compute the additional energy-per-bit E_s from the subsequent retransmission (assuming the same I_o) required to increase the measured E_s/I_o of the received signal to the required E_s/I_o. The information (e.g. the additional E_s) can be transmitted to the source device which adjusts the transmission gain of the retransmitted symbols to obtain the additional E_s required by the destination device. For each retransmission, the destination device can update the received E_s/I_o for the accumulated symbols. The destination device can then recompute the required additional E_s if the decoding still results in a packet error.

[1058] In the present invention, symbol repetition is performed only if the data rate of the packet is less than full rate. If the data rate for the new packet is at full rate, there are no repeated symbols which can be used for retransmission of the packet received in error. Therefore, the present invention can be implemented in conjunction with another retransmission protocol at a higher layer. One such scheme is the radio link protocol (RLP) which is defined by the IS-657 standard. The RLP layer can delay the transmission of the new data packet to allow retransmission of the packet received in error.

[1059] In the second embodiment, the packet received in error is retransmitted on an additional code channel which is available for transmission to the destination device. One major advantage of this embodiment is that the retransmission of the packet received in error is independent of the transmission of the new packet. Therefore, the number of repetitions, the power level, and the code rate do not need to be changed to accommodate the retransmission. Furthermore, the second embodiment allows the source device to retransmit even if the new packet is a full rate frame (i.e. when no code symbols are repeated in the frame). An additional advantage of the second embodiment is the ease of placing the additional code channel on a quadrature channel from the regular traffic channel to reduce the peak to average amplitude variation which can degrade the system performance. The pilot channel, the regular traffic channel, the power control channel, and the additional code channel can be organized to balance the I and the Q channels in the QPSK or OQPSK modulation.

[1060] The various modes of data retransmission described above can be used for retransmission of an entire packet or a partial packet. For some communication systems, it may be possible to monitor the quality of transmission link over the duration of a packet. In the exemplary embodiment, the link quality can be monitored by measuring

E_S/I_O in the manner described in the aforementioned U.S. Patent No. 5,903,554. In this case, it may be more economical to retransmit only the portion of the packet corresponding to the time period when the transmission link quality is poor (e.g., below a predetermined threshold). An indication of the time duration wherein the link quality is poor can be transmitted to the source which then retransmits only that portion of the packet corresponding to the noted time duration. The retransmission of the packets received in error, as described above, is applicable for data retransmission on the forward link and reverse link.

[1061] From the above discussion, symbol accumulation as used in this specification refers to the accumulation of the energy of a transmission of a data packet with the energy of one or more retransmissions of an entire or partial packet. Symbol accumulation also refers to the accumulation of identical code symbols (through addition and/or replacement of code symbols and using the same code rate) and the accumulation of different code symbols (through interleaving and using lower code rates).

V. Processing of the Retransmitted Packets

[1062] If error correcting coding is used for data transmission, full retransmission of the packet received in error is not required to correctly decode the packet. In

the present invention, the destination device decodes the received packet and performs the CRC check to determine whether the packet was received in error. If the packet was received in error, the symbols which comprised the packet received in error are stored for subsequent decoding. In the exemplary embodiment, the storage can be implemented using a storage element or one of any number of memory devices that are known in the art, such as RAM memory devices, latches, or other types of memory devices.

[1063] The source device retransmits the packet received in error in one of the methods described above. The destination device receives the retransmitted packet, accumulates energy of the retransmitted packet with the energy already accumulated for the packet received in error, and decodes the accumulated packet. The additional energy of the retransmitted packet increases the likelihood that the accumulated packet can be decoded correctly. The probability of error of the accumulated packet is typically substantially less than the original received packet since a large amount of energy may have been accumulated from the original transmission and the retransmissions.

[1064] In the exemplary embodiment, the energy accumulation is performed on a symbol by symbol basis. For each symbol, the combined scalar value (from combiner **640**) of the retransmitted symbol is coherently combined with the scalar value which has been accumulated for this data

symbol. The accumulation can be accomplished with an arithmetic logic unit (ALU), a microprocessor, a digital signal processor (DSP), or other devices programmed or designed to perform the functions disclosed herein. Again, coherently combining takes into account the sign of the scalar value. Coherent combination performs the maximal ratio combining of the signals received from the transmission and retransmissions. In this regard, the retransmissions can be viewed as the outputs from additional fingers (or correlators **610**) of a rake receiver. The retransmissions also provide time diversity for the data transmission.

[1065] In the exemplary embodiment, the accumulated scalar value may be manipulated before subsequent demodulation and decoding. The accumulated scalar value of each symbol is a soft decision value which is typically represented as an m-bit signed integer. The soft decision values are eventually provided to Viterbi decoder **814** for decoding. The performance of Viterbi decoder **814** is influenced by the number of bits and the range of the soft decision values. Specifically, for each code branch, the branch metric calculations compares the soft decision values for that code branch to an expected value to obtain a branch metric. The branch metric are then used to defined the maximal likelihood path which results in the decoded bits.

[1066] As energy is accumulated for each symbol from the retransmissions, the soft decision values have tendency to increase in value. Therefore, it may be necessary to rescale the soft decision values with a gain factor A_v before Viterbi decoding. Because the soft decision values are derived from an accumulation of energy from multiple transmission and retransmissions, it is preferable to maintain A_v=1.0. As the soft decision value increases, the confidence in the correctness of that symbol increases. Rescaling the soft decision value to a smaller value to fit within a range can introduce quantization error and other errors. However, other system factors (e.g. E_b/I_o of the received signal) may dictate that the soft decision values be rescaled for an improved performance. In the exemplary embodiment, the scaling can be performed with an arithmetic logic unit (ALU), a microprocessor, a digital signal processor (DSP), or other devices programmed or designed to perform the function disclosed herein.

[1067] Since the branch metric calculation circuit within Viterbi decoder **814** is typically designed with a predetermined number of bits, it is probably necessary to clip the soft decision values. To maintain accuracy, the accumulated scalar values can be stored as unclipped values and the clipping can be done prior to the Viterbi decoding step.

[1068] In a system architecture wherein the pilot signal is not transmitted concurrently with the data transmission, the combination of the data symbols from the transmission and retransmissions is accomplished by another embodiment. An example of such architecture is the reverse link implementation which conforms to the IS-95A standard. It is preferable to accumulated the scalar values according to the signal-to-noise ratio (S/N) of the received signals. At the destination device, the energy S of the desired signal (e.g. the retransmitted packet) can be computed after the despreading with the long PN code and the short PN codes. The total energy of the received signal can be computed and represented as $\sqrt{S^2+N^2}$. Since the received signal is predominantly comprised of the interference (e.g. N>>S), N is approximately equal to $\sqrt{S^2+N^2}$. Thus, the destination device accumulates the scalar values from the transmission and retransmissions according to the equation:

$$y_i = \sum \frac{\bar{s}_{ij}}{|N_{ij}|} \approx \sum \frac{|\bar{s}_{ij}|}{\left(\sqrt{S^2+N^2}\right)_j}, \tag{1}$$

where y_i is the accumulated scalar value for the i^{th} symbol, $\bar{s}_{ij}$ is the vector of the desired signal for the i^{th} symbols of the j^{th} transmission, $|\bar{s}_{ij}|$ is the scalar value from filter **624** for the i^{th} symbols of the j^{th} transmission,

and $\left(\sqrt{S^2+N^2}\right)_j$ is the total energy of the received signal for the j[th] transmission. $\bar{s}_{ij}$ can be approximated with the scalar value $\left|\bar{s}_{ij}\right|$ from filter **624**. Also, $\sqrt{S^2+N^2}$ can be measured for each data transmission or retransmission. From equation (1) the scalar value of each symbol in the packet is scaled by the gain G= $\left(\sqrt{S^2+N^2}\right)_j$ before accumulation.

[1069] In the present invention, the total energy $\sqrt{S^2+N^2}$ of the received signal can be computed on a frame-by-frame basis or on a symbol-by-symbol basis. Symbol-by-symbol basis allows the destination device to adjust the gain of each symbol to take into account fast changes in the channel condition.

[1070] In the present invention, the accumulation of the energy from additional retransmissions allows the destination device to correctly decode the packets received in error. The retransmission allows the communication system to operate at a higher frame-error-rate (FER) than nominal because of the ability to correctly decode the packets with a minimal expenditure of system resource, thereby improving the reliability of the data transmission and possibly increasing the capacity of the system. Furthermore, the retransmission at a subsequent time provides time diversity and improves the reliability of the

data transmission. However, operating at a higher FER necessitates the retransmissions of more packets and can increase the complexity of the communication system.

[1071] The previous description of the preferred embodiments is provided to enable any person skilled in the art to make or use the present invention. The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

WHAT IS CLAIMED IS: